Effects of Calcitic Lime and Dolomic Lime in Permanent Deformation Performance of Gap-Graded Mixtures With Asphalt Rubber

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ABSTRACT

Increasing traffic volume and gross weight overloading have contributed to the accelerated degradation of asphalt pavements. One of the main distress modes in flexible pavements is the premature development of permanent deformation, compromising safety and trafficability of the road users. Aiming at durable materials with a superior performances, the incorporation of hydrated lime to asphalt concretes has been gaining relevance. The present research sought to evaluate the performance of the permanent deformation of Gap-Graded asphalt mixtures designed with two different limes, namely calcitic and dolomitic; both using asphalt rubber binder. Four mixtures were studied: two hot mix asphalt (HMA) and two warm mix asphalt (WMA). The evaluation of the performance regarding the permanent deformation was carried out in the laboratory using a uniaxial repeated load test apparatus to determine the flow number parameter of each mix. Tensile strength tests and resilience modulus were also performed. The results showed that the mixtures with calcitic lime (HMA and WMA) presented a superior number of cycles to failure; the calcitic HMA presented a 35% superior performance and the calcitic WMA presented a 70% superior performance in relation to the respective dolomitic mixtures.

Keywords: Permanent Deformation, Flow Number, Asphalt concrete, Calcitic lime, Dolomitic lime.

1. INTRODUCTION

The road network is the main transportation infrastructure available in Brazil. More than 50% of goods transport relies on highways. However, this modal presents quality and infrastructure deficiencies that only aggravates over time [1].

The significant importance of this modal leads to a continuous search for more durable and resistant materials. Permanent deformation in the near surface of pavements reduces the highway riding quality and safety, as well as increase operating costs.

Accumulated deformation can lead to structural insufficiency and potential loss of grip in wet conditions [2]. The wheel track is caused by the permanent deformation and flow around the wheel path travel that occurs on the asphalt pavements [3]. Rutting develops from the progressive accumulation of small permanent deformations from each load application. This defect becomes frequent in lanes of slow heavy traffic, being severely aggravated by high temperatures and braking and acceleration movements. For the reasons aforementioned, this study aims to assess the behavior of gap-graded mixtures with asphalt rubber regarding permanent deformation susceptibility when calcitic and dolomitc lime is added to the mixture.

2. LITERATURE REVIEW

2.1 Use of Hydrated Lime in Asphalt Mixtures

In the 1970s the quality of asphalt binders in the USA declined due to the oil crisis. This led to an increased damage caused by moisture and thermal cracks of the asphalt pavements, becoming the key pavement degradation cause [4].

The raising frequency of these degradation mechanisms motived the use of several additives for asphalt mixtures in order to limit damages due to moisture. At that time, the use of hydrated lime in asphalt mixtures proved to be effective in mitigating the premature road degradation [5].

Currently, lime has been used to prevent moisture damage and also to improve the resistance to permanent deformation of coatings in various countries [6].

In the USA, it is estimated that 10% of the asphalt surface layers produced have the incorporation of hydrated lime [7]. In Brazil, lime has growing use in asphalt mixes for the same reasons.

2.2 Permanent Deformation of Asphalt Mixtures

Permanent deformation of asphalt mixtures is one of the main pavement failure mechanisms worldwide. There are two types of deformation in the pavement, i.e., structural deformation and non-structural deformation. The structural deformation involves all the layers of the pavement, on the other hand, the non-structural deformation is only associated with the permanent deformation in the asphaltic layers, which is usually accompanied by the lateral "shoulders" [8]. For bituminous materials, the permanent deformation depends largely on the temperature, and secondly the loads and the loading time [9]. Figure 1 shows the process of permanent deformation of the asphalt coating.

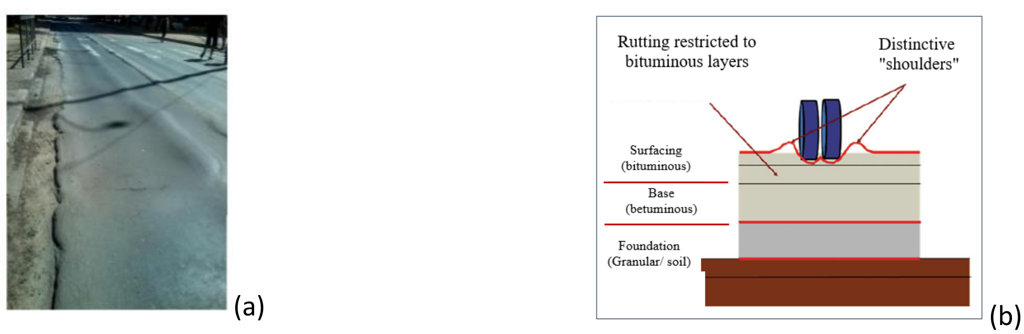

FIGURE 1: Rutting formed by the permanent deformation of the material (a) and non-structural deformation scheme of the asphalt layer (B) (author and adapted from [8])

The deformation in asphalt mixtures due to the passage of a single vehicle is typically very small, but the consecutive passage of vehicles can lead to considerable permanent deformation in the pavement accumulation [8].

Permanent deformation followed by the fatigue process was alredy apponted the process as the main contributor to the loss of pavement quality in the United Kingdom [9]. Any approach to pavement designs should limit the potential for permanent deformation and fatigue so that the quality of the pavement does not decay rapidly. Changes in traffic and loading characteristics contributed significantly to deformation in a predominant mode of failure in the useful life of flexible pavements in the 1980s and 1990s [2].

The effect of permanent deformation in the asphalt mixtures, besides being bound to the action of the loads, is strongly dependent on the characteristics of its constituent material: aggregates and asphalt binder.

2.3 Uniaxial Repeated Load Test (Flow Number)

The uniaxial repeated load test is the laboratory test that has been gaining national prominence for the evaluation of the permanent deformation of asphalt mixtures [11;12; 13; 14; 15].

The test consists of the application of a cyclic load of uniaxial compression in the haversine format, with a frequency of 0,1 s of loading followed by 0,9 s of rest and the accumulated deformations are obtained through the number of cycles [16].

The load applied during the charging phase is 204 (± 4.0) kPa and during the standby phase, 5% of the charging load is applied. The test is performed on cylindrical specimens measuring 150 mm (± 2,5 mm) in height and 102 mm (± 2,0 mm) in diameter and VV of 7% (± 05%), subjected to a temperature of 60 ° C (with the prior conditioning of at least 3 hours). Typically, the test is carried out up to 7,200 cycles (2 hours) or until the sample creeps (ruptures) [16].

The test response is seen in graphs of cumulative permanent deformation versus a number of cycles. The assay can be divided into three stages as seen in Figure 2.

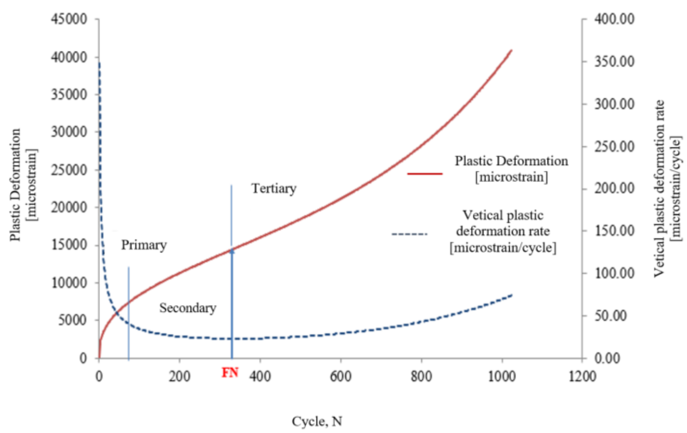

FIGURE 2: Relation between the accumulated total deformation, the rate at which the deformations occur and the number of cycles

The number of cycles where the test passes from the second stage to the third stage is referred to as Flow Number (FN). The FN is the number of the cycle in which the strain rate is minimal and in which the specimen begins to enter the constant shear phase, as can be observed in Figure 2.

The FN test is increasingly being used as an evaluation criterion for asphalt mixtures as reference to permanent deformation. Thus, some authors suggest reference values of the FN for traffic levels, as per Table 1.

TABLE 1: Comparison of test parameters and suggested values of FN for different levels of traffic

Author	Axial tension (Kpa)	Temp. (°C)	Vv (%)	Traffic Level (FN least)			
				Light	Medium	Heavy	Extremely Heavy
				< 3×10^6	[3×10^6 ;1×10^7]	[3×10^7; 1×10^7]	> 3×10^7
AASHTO TP 79-15	600	-	7 ± 0,5	-	50	190	740
Bonaquist (2012)	600	49,6	7	15	50	135	415
Nascimento (2008)	204	60	7 ± 0.,5	-	300	750	-

(Source: adapted [17]; [18]; [10])

3. MATERIALS AND METHODS

The aggregates and asphalt binders characterization was carried out according to standardized acceptance and characterization tests, aiming the evaluation of the material's usability in the mixtures.

3.1 Stone aggregates

The aggregates used in the research are of basaltic origin Serra Geral formation, with three different fractions 3/4 ", 3/8" and stone powder, the characterization test were within the imposed limits.

3.2 Asphalt binders

The asphalt binder used was AB-8 with PG-76-XX* (Performance Grade). In addition to the binder, a surfactant additive was used for the warm blends, it was perceived that the additive binder fulfilled the Brazilian requirements [19].

3.2 Hydrated lime

Two limes, one calcitic and another dolomitic were used in the research. Table 2 presents lime's characteristics.

TABLE 2: physical characteristics of lime

Characteristics	Calcitic lime	Dolomite lime
Total calcium oxide (CaO),%	72,2	37,2
Available calcium oxide (CaO available),%	68,0	18,0
Magnesium oxide (MgO),%	0,6	25,4
Insoluble wastes,%	0,9	7,2
Loss to Fire (1000 ° C),%	24,9	29,3

3.3 Grading curve

The mixture grading composition was designed to fit the material in the Gap-graded curve of the DNIT (National Department of Infrastructure and Transport). Hence, 15% of the maximum aggregate size ¾", 46,5% of the 3/8" gravel, 37% of stone powder and 1,5% of dolomitic lime (mixtures named as HMA1 and WMA1) and 1,5% calcite lime (mixtures HMA4 and WMA4).

3.4 Asphalt Mixtures

To obtain the binder content of the mixture, the Marshall design methodology was used. The design was carried out for the HMA and it was only checked whether the binder content was suitable for the WMA, as per previous studies recommendation [20], so the design content used in the four blends was equal to 7%.

3.5 Tensile strength

The test of tensile strength by diametrical compression was carried out following the Brazilian standard procedures. The test consists of applying a static compression load at a constant speed of 0,8 mm/s, in cylindrical specimens with Marshall dimensions, and temperature of 25 °C. The load is applied until the sample collapses. It is assumed that this rupture occurs due to tensile stresses generated in the plane perpendicular to the load application [21; 22].

3.6 Diametral Compression Resilience Module

The resilience modulus was performed according to the Brazilian normative procedures. The test is the relation between the tensile stress applied repeatedly in the vertical diametral plane of a cylindrical CP Marshall dimensions and the specific recoverable deformation corresponding to the applied voltage [23; 24]. The assay was performed at 25 °C and repeated loading was applied, with 0,1 s of load and 0,9 s of load resting. The horizontal deformation suffered by the sample was measured by a Linear Variable Differential Transformer (LVDT). The loading applied in the assay was 15% of the tensile strength value, which was previously determined

3.7 Specimens for the Flow Number Test

The specimens that were used for the test were compacted in a giratory compactor due to the need of samples with diameters of 100 mm and height of 150 mm. The compaction of the samples was directly in these dimensions, looking for air voids 7% ± 0.5%.

3.6 Execution of the Uniaxial Repeated Load test

The test is used to determine the resistance to permanent deformation of asphalt mixtures through parameter FN. The tests were performed in a hydraulic universal testing machine model MTS 810 UTM Test System. The tests were carried out according to the specifications of Brazilian normative [16].

First, the specimen was conditioned in the temperature chamber of the MTS at 60 °C for at least 3 hours, the temperature was controlled through a counterfeit specimen with an internal temperature sensor and another external temperature sensor.

Subsequently, the specimen was positioned for testing. While the test was performed the equipment software recorded, in real time, the displacement curve versus cycles, being possible to follow the stages of evolution of the test. The vertical displacements were collected for two extensometers coupled to the lateral (sample) side of the sample (diametrically opposed), the Figure 3 shows a test sample ready to be tested.

FIGURE 3: Test sample prepared for the test

4 RESULTS

As previously discussed, three samples of each mixture were analyzed so that there was a representative analyzed sample, the Flow Number cycle, and the results obtained during the tensile strength test as well as the Resilience Module are shown in Table 3.

TABLE 3: Results of test for each mixture studied

Mixture	HMA 1 AB-8 (dolomitic)	WMA 1 AB-8 (dolomitic)	HMA 2 AB-8 (calcitic)	WMA 2 AB-8 (calcitic)
Tensile Strength 25°C (MPa)	0,96	0,86	1,01	0,92
Diametral Resilience Module 25°C (MPa)	3097	2670	4119	4439
FN, cycles	275	94	437	332

The HMA 2 and WMA 2 mixtures, measured with calcitic lime, showed superior performance compared to mixtures with the dolomitic lime (HMA 1 and WMA 1), which is explained by the higher concentration of calcium dioxide available in calcitic lime. The HMA 2 blend had a 35% higher performance than the HMA 1 and the WMA 2 blend presented 70% higher performance than the WMA 1 blend. This showed that the warm mixtures were more susceptible to the addition of lime. The WMA 1 obtained the lowest value of FN, this may have occurred due to the interaction of the dolomitic lime and the warm mixture additive

5. FINAL CONSIDERATIONS

This work aimed to evaluate the performance to permanent deformation resistance of HMA and WMA with an addition of hydrated lime and focus on the parameter of Flow Number. From the results, the following conclusions are noted:

• When analyzing the mixtures it was observed that the mixture designed with calcitic lime had superior performance to that of the mixture of dolomitic lime, proving the benefits of calcite lime, which has the highest concentration of available calcium oxide;

• When comparing the results of FN, cycles with the values stipulated in Table 1 for the use of the field mixtures, it was verified that the mixtures with calcitic lime can be used in medium traffic pavements, while the mixtures with dolomitic lime presented lower performance to the minimum stipulated for that category of traffic for Brazilian researchers [10].

• The insertion of calcitic lime was beneficial in increasing the tensile strength and resilience modulus of the analyzed asphalt mixtures.

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